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Wheat Yield Prediction based on IOWA Operator Combination Gray BP Neural Network

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Abstract

In this paper, we use the combination prediction method to predict the future grain yield in China. In order to improve the accuracy and reliability of wheat yield prediction, we established a combination of grey prediction model and BP neural network model, and constructed a combination grey neural network prediction model based on IOWA operator with minimizing the sum of squared error as the optimization objective. The results show that:the combined prediction model integrates the advantages of each single prediction model, improves the prediction accuracy and reduces the prediction result error at the same time, whichprovides a feasible and effective research method for the prediction of wheat yield. And the model was used to further predict the wheat yield in China from 2022 to 2024 on this basis.

Keywords

Gray Prediction Model; BP Neural Network Model; IOWA Operator; Combined Prediction.

1. Introduction

At present, the application of forecasting technology is becoming more and more extensive, and the requirements for forecasting accuracy are also increasing. In real life, various forecasting methods usually give useful information in only one direction, and when one forecasting method is used, other relevant and useful information is bound to be omitted, resulting in a relative bias in the forecasting results to fully utilize the effective information.

Combined prediction is the use of two or more methods to predict the same target, and then the results of each individual prediction are weighted and synthesized. From the synthesis principle, it can be seen that even if one method has a poor forecasting effect, it can be improved by combining it with other forecasting methods. Compared with a single prediction method, the combined prediction method can maximize the use of effective information, which is more scientific and effective.

Because the combined prediction method has strong scientific and practicality, this study tries to use it to predict the grain yield in China, which is one of the three major grain crops in China, and its yield is crucial for the country's food security. Therefore, it is very important to improve the accuracy of prediction of wheat yield. Therefore, choosing appropriate scientific principles and prediction methods to predict wheat yield to a certain extent, this statement implies that it is very important to stabilize wheat production and advance food security, which is also one of the important tasks currently facing.

Currently, wheat forecasting technology has become more mature, which puts higher requirements on the accuracy of forecasting. On this basis, it is proposed to utilize the combined forecasting method, which organically combines the respective advantages of individual forecasting models to make them have higher forecasting accuracy. The traditional joint prediction method is to have two or more prediction methods for the same problem, and in the combination, the information provided by different methods is integrated, so that the

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prediction effect can be maximized. Its basic form is to assign different weights to each prediction method. Since the performance of each individual prediction model is not the same at each point in time, which leads to a large error at a certain point in time, and subsequently leads to the instability of the overall performance.

In this paper, we propose a prediction method based on the prediction accuracy of each individual prediction model at each time point. Compared with other traditional combined prediction methods, the model is more stable and reasonable. It provides new methods and approaches for the prediction of wheat yield.

Assuming that there are N prediction methods for the same problem, the combination prediction theoretical model is Then the combination prediction theoretical model is:

$$Y_t = W_1 Y_{t1} + W_2 Y_{12} + \cdots + W_N Y_{tN}, \quad \sum W_j = 1$$

Where represents the predicted value of the jth method in time t; then represents the predicted value of the combination prediction in time t.

The following is the relevant calculation method of the weights: how to select the appropriate weighting factors in the combination prediction, and different methods of weight selection, which can be applied to improve the accuracy of the prediction. On this basis, the variance inverse method is selected, which is used. This method is simple and easy to implement with good results.

The expression formula is:

$$W_j = (D_j^{(-1)}) / (\sum_{(j-1)} D_j^{(-1)}), E\sum_{\text{j-1}} W_j = 1, j = 1, 2, \ldots, N$$

D_j is the sum of squared errors for the jth model:

$$D_j = \sum_{\text{j=1}}^{n} (\text{Y}_\text{i} - \hat{\text{Y}}_\text{ij})^2$$

2. Combined Prediction Model based on IOWA Operator

Let be $(v_1, a_1), (v_2, a_2) \ldots, (v_n, a_n)$ a two-dimensional array of n:

$$f_w\left[((v_1, a_1), \quad (v_2, a_2), \quad \ldots, \quad (v_n, a_n))\right] = \sum_{i=1}^{n} w_i a_{v-index(i)}$$

Then the function f_w is called the n-dimensional induced ordered weighted averaging operator, that is, the IOWA operator. will be sorted in order from large to small, then the lower number of the largest number is marked as, and the weighted coefficient vector satisfies the following formula:

$$\sum_{i=1}^{n} w_i = 1, w_i \geqslant 0, i = 1, 2, \cdots, n$$

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In the above formula, the number $a_1, a_2, ..., a_n$ is ordered weighted average after sorting according to the order of induced values.
Based on the establishment of the combined forecasting model of IOWA operator, we set:

$$v_{it} = \begin{cases} 1-|(x_i - x_{ii})/x_t| & |(x_i - x_{it})/x_t| < 1 \\ 0 & |(x_i - x_{it})/x_t \geq 1 \end{cases}$$

In the prediction method proposed in this paper,x_{it}represents the prediction accuracy of the i th prediction method at the time t, which is the prediction value of the i th prediction method at the time, and $x_t$represents the actual statistical value at the time t. Based on this, a two-dimensional array of the prediction accuracy of the n th prediction method at the time and its predicted value is obtained:

$$(v_{1t}, x_{1t}), \quad (v_{2t}, x_{2t}), \quad ..., \quad (v_{nt}, x_{nt})$$

Let be $W = (w_1, w_2, \cdots, w_n)^T$a weighted coefficient vector. According to the above formula, the combined prediction value at the moment is the following formula.

$$f_w\left((v_{1t}, x_{1t}), \quad (v_{2t}, x_{2t}), \quad ..., \quad (v_{nt}, x_{nt})\right) = \sum_{i=1}^{n} w_i a_{v-index(i)}$$

Next, we conclude that the sum of squares S of the total combined prediction error in the N period is:

$$S = \sum_{i=1}^{N} (x_t - \sum_{i=1}^{n} w_i x_{v-ind \quad (it)})^2 =$$

$$\sum_{i=1}^{n} \sum_{i=1}^{n} w_i w_j (\sum_{i=1}^{N} e_{v-ind \quad (it)} e_{v-ind \quad (jt)})$$

When establishing the IOWA operator combination forecasting model, based on the minimum sum of squared errors, the model is as follows:

$$s.t. \begin{cases} minS \\ \sum_{i=1}^{n} w_i = 1 \\ w_i \geqslant 0, i = 1,2,\cdots,n \end{cases}$$

Below we make:

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$$E_{ij} = \sum_{i=1} e_{a-index(it)} e_{a-index(jt)}, \quad i\, j=1,2,\cdots,n,$$

Then we call E = (E_{ij}) m×m is the information square matrix of the combined prediction error of the m-order IOWA operator, and the matrix L is the weighted arithmetic average combined prediction model. The model after they are combined is shown in the following formula:

$$\begin{aligned} &minS = L^{\mathrm{T}} EL \\ &\text{s.t.} \begin{cases} R^{\mathrm{T}} W = 1 \\ W \geq 0 \end{cases} \end{aligned}$$

In the above formula :R = $(1,1,\cdots,1)^{\mathrm{T}}$, W is the weighted coefficient vector. If the matrix E is a positive definite matrix, then the model has a unique optimal solution which is:

$$W^* = E^{-1}R / R^{\mathrm{T}} E^{-1} R$$

3. Construction of Wheat Yield Prediction Model

This paper takes the wheat yield data of China from 1996 to 2021 as the research object, and establishes two single prediction models to predict the wheat yield in this period. At the same time, the IOWA operator theory is used to evaluate the corresponding model. By constructing two separate prediction models, the weight distribution of the prediction performance of each individual prediction model at different time points is constructed to construct an optimal combined prediction model.

The essence of the grey prediction model is an exponential prediction model. The prediction theory of the grey process GM model that accumulates the original data over time is to use the cumulative method to generate a set of new data sequences with significant trends for a data sequence. According to the development trend of the new data sequence, a model is constructed to predict it. Using the decreasing method, the original data sequence is restored by reverse operation, so as to obtain the predicted results. On this basis, an improved method is proposed, that is, the method of reducing uncertainty, enhancing uncertainty and enhancing uncertainty. Wheat yield per unit area is a very complex prediction problem. The annual yield per unit area is related to modern science and technology. It also has a great relationship with climate, ecology and other factors.

Combined with the above construction steps, the process of constructing the grey prediction model is as follows:

(1) $T^{(0)}(1), T^{(0)}(2), T^{(0)}(3)\cdots, T^{(0)}(n)$ is the original sequence of wheat yield index, and the result sequence is produced by one accumulation, that is:

$$T^{(1)}(n) = \sum_{k=1}^{n} T^{(0)}(k)$$

(2) The changing trend of the sequence is described by exponential curve or straight line.

$$\frac{\mathrm{d}T^{(1)}}{\mathrm{d}x} + aT^{(1)} = \mu$$

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In the above formula : Using the method of regression analysis, the development coefficient a and the value of grey action are obtained by accumulating the accumulation sequence. Then:

$$[{}^{a}_{\mu}] = (B^{M}B)^{-1}B^{M}Y_{n}$$
$$Y_{n} = [T^{(0)}(2), T^{(0)}(3), T^{(0)}(4)\cdots, T^{(0)}(n)].$$

(3) The following data matrix is constructed.

$$\mathrm{B}=\begin{bmatrix} -\frac{1}{2}[T^{(1)}(1)+T^{(1)}(2)] & \cdots & 1 \\ \vdots & \ddots & \vdots \\ -\frac{1}{2}[T^{(1)}(n-1)+T^{(1)}(n)] & \cdots & 1 \end{bmatrix}$$

Find out the prediction model:

$$\hat{T}^{(1)}(k+1) = [T^{(0)}(1) - \frac{\mu}{a}]e^{-a} + \frac{\mu}{a}$$

Using the above model for prediction, the collected wheat yield data can be input into the model for processing and calculation. The corresponding time series equation of the final grey differential equation is as follows:

$$\hat{\mathrm{T}}^{(1)}(\mathrm{k}+1) = 815026.336\mathrm{e}^{-0.011544937\mathrm{k}} - 805203.336\ 6$$
$$\mathrm{a}=-0.011544937,\ \mu = 9296.021414$$

Table 1. Prediction value of grey prediction model of wheat yield

year	The predicted value of GM model	Prediction Precision	year	The predicted value of GM model	Prediction Precision
1996	10 026.33	0.907	2009	11 649.92	0.995
1997	10 142.76	0.824	2010	11 785.19	0.985
1998	10 260.53	0.935	2011	11 922. 04	0.995
1999	10 379. 68	0.911	2012	12 060.48	0.986
2000	10 500.20	0.946	2013	12 200.52	0.988
2001	10 622. 13	0.869	2014	12 342.19	0.962
2002	10 745.47	0.810	2015	12 485. 51	0.942
2003	10 870.25	0.744	2016	12 630.49	0.949
2004	10 996.47	0.804	2017	12 777.15	0.952
2005	11 124. 16	0.859	2018	12 925.51	0.983
2006	11 253.33	0.963	2019	13 075.61	0.980
2007	11 384.00	0. 960	2020	13227.1	0.975

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Aiming at the problems of low convergence rate and large fluctuation of BP neural network, this project intends to combine Gauss-Newton algorithm with the fastest descent method, and adopt Lev-Enberg-Marquardt optimization method, so that it can accelerate the convergence rate of the network and achieve higher prediction accuracy under the condition of limited data volume. We use BP neural network prediction model to construct wheat yield prediction model. The specific steps are as follows:

(1)The relevant time series x (t) of wheat yield prediction data from 1996 to 2021 was constructed.

(2) The original data is standardized to facilitate the extraction of relevant information. The standardization process is as follows. First, the input data is converted into numbers on [0, 1] and [-1, 1].

$$x' = \frac{x - \min(x)}{\max(x) - \min(x)}$$

x is a set of sample data selected arbitrarily, representing the maximum value in the sample and the minimum value in the sample.

(1)The error value of the learning sample and the mathematical expectation is determined by the length of the predicted correlation time series x(t).

(2) BP network is generated and initialized. The L-M optimal algorithm is used to correlate the normalized data for network learning.

(3) According to the number of sample data sets, the correlation function is selected for related training. In this paper, the trainlm function is selected for network training. Finally, the standard of training completion is that the training results should meet the expected error or the number of times to reach the upper limit training.

Finally, according to the neural network that has been completed and has reached the corresponding error accuracy, the wheat yield in China from 2022 to 2024 is predicted. And the process of continuous learning and improvement.

When training the BP network, the maximum number of iterations is set to 500. Need 0.001 error target ; the learning function of the network is trainlm.

Table 2. Prediction of wheat yield by BP neural network model

year	The Predicted value of GM model	Prediction Precision	year	The predicted value of GM model	Prediction Precision
1996	10 831.0	0.980	2009	11453.2	0.989
1997	12488.6	0.987	2010	11877.2	0.977
1998	10767.1	0.980	2011	11779.8	0.992
1999	10823.2	0.951	2012	12115.6	0.989
2000	9700.6	0.973	2013	12038.6	0.974
2001	9022.8	0.961	2014	12547.9	0.977
2002	9489.2	0.949	2015	13066.8	0.986
2003	8415.0	0.973	2016	13001.7	0.985
2004	8934.4	0.971	2017	13117.4	0.977
2005	9387.2	0.963	2018	13594.1	0.965
2006	10487.7	0.966	2019	13539.2	0.987
2007	10711.3	0.978	2020	13548.7	0.957

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The grey neural network prediction model based on IOWA operator combination prediction is as follows : The prediction value and prediction accuracy of the two types of one-sided prediction obtained from the above two tables are based on the prediction accuracy of the model as the guide value, and each guide value is arranged in order of size, and then each guide value is weighted and averaged in order. This time, we used Lingo software to solve the problem. On the basis of this formula, we can get a unique and optimal solution vector. At the same time, the combined predicted value at the moment is calculated as follows:

$$f_w[v_{1t}, x_{1t}),(v_{2t}, x_{2t})]=0.925_{x_{v-ind\ \ (1t)}} + 0.070_{x_{v-index(2t)}}$$

Next is the result of the combination forecast, as shown in the following table:

Table 3. The predicted value of wheat yield combination forecasting model

year	Combined forecast value	Prediction Precision	year	Combined forecast value	Prediction Precision
1996	10770.45	0.975	2009	11634.56	0.994
1997	12325.15	0.998	2010	11790.98	0.984
1998	10730.6	0.977	2011	11911.78	0.994
1999	10780.78	0.946	2012	12110.67	0.987
2000	9758.67	0.978	2013	12188.58	0.985
2001	9139.64	0.973	2014	12543.88	0.965
2002	9578.00	0.938	2015	13054.36	0.981
2003	8598.87	0.995	2016	12987.67	0.986
2004	9087.56	0.986	2017	13093.29	0.985
2005	9513.89	0.975	2018	12965.34	0.987
2006	10542.89	0.970	2019	13504.67	0.989
2007	10759.83	0.982	2020	13531.74	0.985

Comparative analysis of the results of the three prediction models: Through the comparative analysis of the predicted values of the above three prediction models, combined with the relevant data of China 's statistical abstracts, it is not difficult to find that on the whole, the combined prediction model is closer to the actual value, and is the closest to the real value. The prediction method, and the range of error fluctuations of the combined prediction model is significantly smaller than the single prediction model. In summary, the combination prediction model is more effective than the single prediction model in the prediction of wheat yield. Based on this, the combination prediction model is used to predict the wheat yield in 2022-2024.

4. Wheat Yield Prediction

The comprehensive prediction model based on IOWA operator has high prediction accuracy for sample data, and the prediction results are better than the other two single prediction models. Therefore, it can be applied to the prediction of wheat yield in the next two years.

Because there is no actual value to compare the prediction results of the subsequent period, the prediction results of each period cannot be calculated. Moreover, the prediction accuracy cannot be used as a derivative variable of each individual prediction model to determine its weight. In order to facilitate the calculation, the weight of each individual prediction model during the forecast period is simplified, and the weighted average of the two individual prediction models is performed. Based on this, a grey prediction method based on BP neural

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network is proposed. Therefore, two single prediction models are used to assign the corresponding weights to the predicted values of wheat yield in China in the next two years. Finally, based on the IOWA operator combined grey neural network prediction model, the predicted values of wheat yield in the next two years are calculated. The results are shown in the following table.

Table 4. Prediction of wheat yield in the next two years

year	The predicted value of GM model	BP neural network prediction	Combined prediction value
2023	13684.65	14198.64	13878.8
2024	13878.12	14230.34	14134.4

5. Conclusion

The IOWA operator is used to establish a combined forecast from 1996 to 2021, and compared with two single prediction models. Through comparison, it can be seen that based on the IOWA operator combined grey neural network prediction model, it can effectively reduce the interference of redundant data in the prediction process. Therefore, on the whole, the accuracy of prediction is higher than that of a single prediction model, and the prediction model is more stable. It provides an effective research method for the prediction of wheat yield. Based on this, it is of practical significance to apply this combined model to the prediction of wheat yield in the next two years in China.

References

[1] Ding Chenfang. Application of combined model analysis method in grain yield forecasting in China [J]. Research on Agricultural Modernization, 2007(1) : 101-103.

[2] Chen Huayou, Liu Chunlin. Combined forecasting method based on IOWA operator[J]. Forecasting, 2003(6) : 61-65.

[3] Wang Yangmei, Yang Guiyuan, Yuan Hongjun. Combined forecast of China's grain production based on induced ordered weighted average operator[J]. Journal of Heze College, 2013, 35(2):14-18.

[4] Cao Feifei. Application of gray system theory in grain yield prediction[J]. Practice and understanding of mathematics, 2017, 47(13):310-312.

[5] Teng Kai. Optimization of process parameters of liquid injection wire cutting based on BP neural network L-M optimization algorithm. Machine Tools and Hydraulics,2016,44(15):137-141,146.

[6] Wu Yan, Du Dong. Simulation prediction of grain production in Jiangsu Province based on improved BP neural network[J]. Microcomputer Application, 2009, 25(6):1-4.

[7] Kuang Na, Tang Qiyuan, Zheng Huabin. Study on the differences in cooking flavor quality and starch structure and properties of regenerated seasonal rice in different regions [J]. Journal of Nuclear Agriculture, 2021, 35(7):1678-1686.

[8] Zhang Chao. Analysis of cooking flavor quality and digestive characteristics of southern semi-glutinous japonica rice based on starch structure[D]. Yangzhou: Yangzhou University, 2021.

[9] Wei Xiaodong, Zhang Yadong, Zhao Ling, et al. Formation of rice flavor substance 2-acetyl-1-pyrroline and its influencing factors[J]. Chinese Rice Science, 2022, 36(2): 131-138.

[10] GUO Li-Jin,ZHANG Jia-Hao. Wheat yield prediction based on IOWA operator combined gray neural network[J]. Grain and Oil,2022,35(10):26-30.

[11] Chen, Huayou. Theory of effectiveness of combinatorial prediction methods and its application[M]. Science Press, 2008.

[12] Wang YL, Chen HY. Forecasting and decision-making methods and applications based on integrated operators [M]. Anhui University Press, 2014.